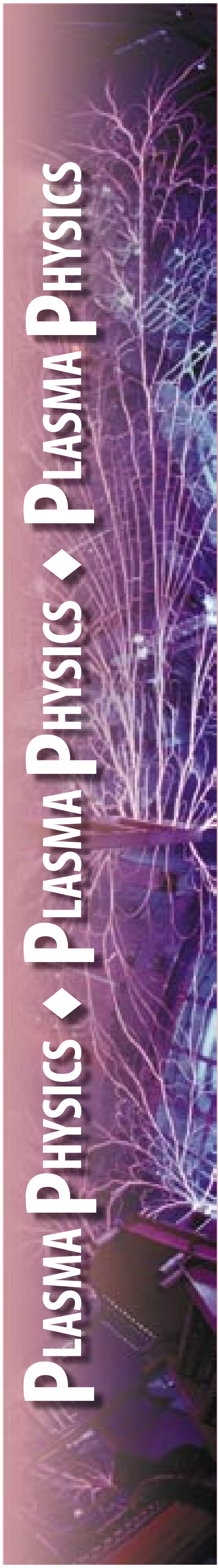

Experimental Physics Using the Z Accelerator at Sandia National Laboratories

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The natural world is constantly attempting to reach an equilibrium state most simply thought of as a state in which quantities such as temperature or density are uniform throughout a volume. When quantities such as temperature vary from one point to the next in the volume, these differences can act to produce a force that tries to restore that quantity to a uniform state. These restoring forces can lead to familiar processes such as water being ejected from the end of a hose because of the pressure difference between the inside and the outside of the hose (a pressure gradient). The flow of heat down a bar of metal that has been heated on one end by a torch is another process (thermal diffusion) created by the difference in temperature from point to point along the bar (a thermal gradient). Forces resulting from gradients are less familiar than forces such as gravity, but they can be the driving engine in processes from the very small (mixing of two different liquors in a mixed drink or the rate of chemical reactions in a retort—both driven by concentration gradients) to the extremely large (mass ejection, astrophysical jet creation, and shock formation—all driven by energy density gradients in supernova explosions). While forces that result from gradients play a role in daily life, they can also play a dominant role in less mundane fields such as astrophysics and the physics involved in nuclear weapons.

Radiation Transport

The concept of a radiation temperature (T_{rad}) and of the transport of radiation through stellar systems arises from a logical extension of the familiar concepts discussed above (e.g., heat emission from a thermally warm object). These concepts extend from infrared radiation from a hot metal bar at a few 100 K all the way to x-rays emitted from an extremely hot object (e.g., a blackbody radiator) with an equivalent temperature in the million-degree range. Understanding radiation transport is important because it plays a prominent role in the evolution of stars and in the functioning of a nuclear weapon. Like thermal temperature gradients that cause the diffusion of heat down a metal bar, T_{rad} gradients cause the transport of radiation through systems. For example, radiation from a star is transported from the high T_{rad} region deep within the star where it was created out into the cold surrounding interstellar region. On its way out, the radiation moves through regions where various radiation-transport models may be valid—all driven by T_{rad} gradients. Transport processes in a star are the subjects of intense study using astrophysical simulations.

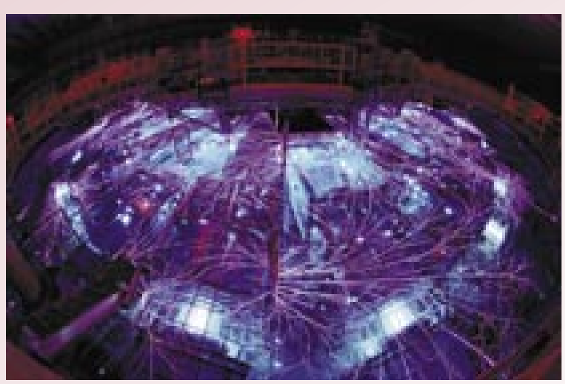


Figure 1. Bird's eye view of the Z accelerator as it fires.

The Z pulsed-power accelerator at SNL generates an environment in which large T_{rad} gradients exist at temperatures of about 2 x 10^6 K (220 eV). This extreme environment allows us to study the underlying physics behind radiation transport. Because of the importance of radiation transport, experimental data are needed to ensure that we have the correct physics understanding, models, and simulation tools. Data from experiments on Z can lead to new models or confirm existing models and thus validate LANL's physics and engineering simulations. Experimental tools like the Z accelerator are needed to produce radiation-transport data and other types of data, including material properties of metals (e.g., beryllium and uranium) of interest to the laboratory.

The Z Accelerator

The Z accelerator reuses the energy-storage system originally built for the ICF PBFAII project at SNL in the early 1980s. The Z accelerator is a high-energy capacitor bank comprised of 36 parallel modules arranged in a circular array. The 36 current pulses are coupled towards the center of the array through a series of pulse-forming networks (PFNs). These PFNs are used to compress the many microsecond current pulses into 100-ns current pulses. After penetrating the wall of a vacuum vessel, the 36 individual current pulses are combined into a single current pulse. This single pulse is then transported into the center of the chamber where it is converted into some form of energy used for an experimental physics study.

The capacitor banks, PFNs, vacuum vessel, and ancillary equipment reside in a several-story building designed for the task. Service utilities in the building provide vacuum, high-pressure air, normal air-conditioning service, and high-voltage service for charging the capacitor bank. Also, a high-capacity crane and a multitude of shielded enclosures (one belonging to P-22) service diagnostic instruments in the electrically hostile environment. The main control room is a shielded enclosure that protects the computer control system when Z fires.

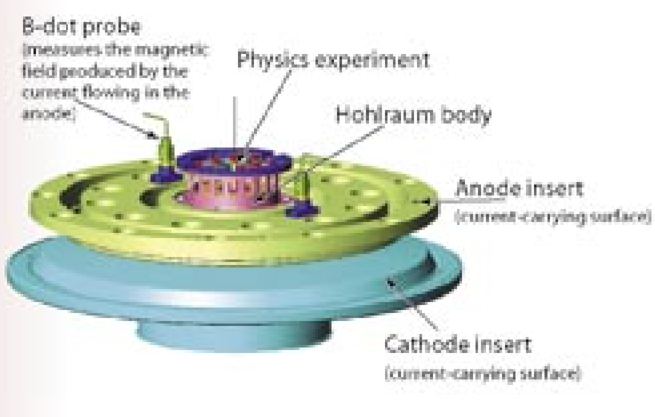


Figure 2. An anode and cathode insert with attached dynamic hohlraum body.

The high-power Z Beamlet Laser (ZBL) was recently constructed as a new capability in an adjacent building to the Z accelerator. (Parts from LLNL's beamlet laser system—the prototype for each arm of the NIF—were refurbished for the construction of ZBL.) The light from ZBL is transported into the Z target chamber through an optical transport system that spans the space between buildings. The ZBL light pulse produces x-rays from a metal foil in the Z vacuum vessel. The x-rays are produced next to a physics experiment at the center of the target chamber. They are typically used as an x-ray backlighter to illuminate the physics experiment and to take a dynamic image of its evolution in a manner similar in concept to DARHT and PHERMEX at LANL.

Figure 1 shows a bird's eye view of the Z accelerator as it is firing. (From the image, one can see why all electronics are generally located in shielded enclosures!) The lightning bolts in the image are above the PFNs. The PFNs reside in low-conductivity water where pulse duration compression from 10 μs to 100 ns takes place for subsequent injection into the target chamber. The discharges (lightning bolts) are due to energy leaking out of the high-voltage switches in series with the PFNs into the surrounding environment. From the water section, the pulse-forming lines feed through an insulating water-vacuum interface and onto a radial magnetically insulated transmission line (MITL), which then feeds the center of the machine where the physics experiment is conducted. Because of the total amount of energy involved (~ 14 MJ at 90 kV) in each discharge, the very center of the MITL has an interchangeable ~ 12-in.-diam insert that holds the physics experiment and the final disposable sections of the anode and cathode current conductors. This insert (Figure 2) is destroyed on each shot. The MITL must be removed and physically cleaned after each shot, which limits the facility to a single shot each day. In an x-ray production mode, Z is the most powerful x-ray source in the world (~ 250 TW in a 3–5 ns pulse) and provides an unmatched tool for radiation driven experiments conducted by LANL and others. X-ray production, x-ray driven experiments, and other experimental uses of Z will be discussed below.

Radiation-Driven Experiments

For production of x-ray radiation, the electrical current flowing in the system is run through a set of very small diameter wires inside a confining structure, known as a hohlraum, which is used to contain any x-ray radiation that is produced from the experiment. The wires collapse toward the center of the vacuum vessel under the magnetic forces acting on them. The 12-in.-diam sacrificial insert (in the configuration shown in Figure 2) is comprised of a final anode and cathode section with a slotted dynamic hohlraum body mounted on top of the anode. Current delivered by the MITL travels radially inward on the cathode and up through a set of 360 tungsten wires, each ~ 10 µm in diameter, located inside the hohlraum body. The current then returns along the top and down the side of the hohlraum body and finally to the capacitor-bank modules via the anode and the MITL. In this configuration, magnetic forces drive the wires radially inward at high velocity until they stagnate near the axis. Their kinetic energy is converted into thermal energy, which radiates away in the form of x-rays that are absorbed and re-radiated inside the hohlraum body. The resultant x-ray flux is used to drive physics experiments either around the periphery of the hohlraum or on the top of it.

Copious amounts of thermal x-rays are produced when an array of wires collapses either onto themselves (as in a vacuum hohlraum, Figure 3) or onto a low-density foam located on the axis of hohlraum (as in a dynamic hohlraum). The vacuum hohlraum can generate an environment with an equivalent blackbody temperature of 145 eV inside a solid-wall hohlraum. The wall of the hohlraum can then be populated with multiple physics packages for studies of radiation flow inside closed geometries and flow through free-standing low-density foams and for studies of aperture closure driven by radiation and shocks that impinge on the gold hohlraum wall.

Alternatively, the dynamic hohlraum produces radiation from a wire array as it impacts upon a low-density foam located in the center of the array, subsequently thermalizing the kinetic energy in the wires and radiating the energy vertically. This radiation can be directed out of the top and bottom of the pinch to a physics experiment above or below the wire array, rather than around the periphery of the hohlraum body as in the case of a vacuum hohlraum. This process produces a much higher-radiation temperature (220 eV) to drive a single package located above the hohlraum for similar studies. A recent radiation-transport experiment that investigated radiation loss through the thin gold wall of a physics package located above the pinch using the ZBL system for backlit imaging is discussed in this report (“X-ray Diffusion through a Thin Gold Wall,” page 84) P Division and SNL use vacuum hohlraums to study both weapons-physics issues and astrophysical jet formation and dynamic hohlraums to study both weapons-physics issues and indirect-drive ICF.

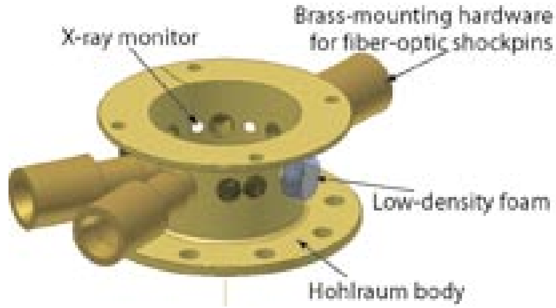


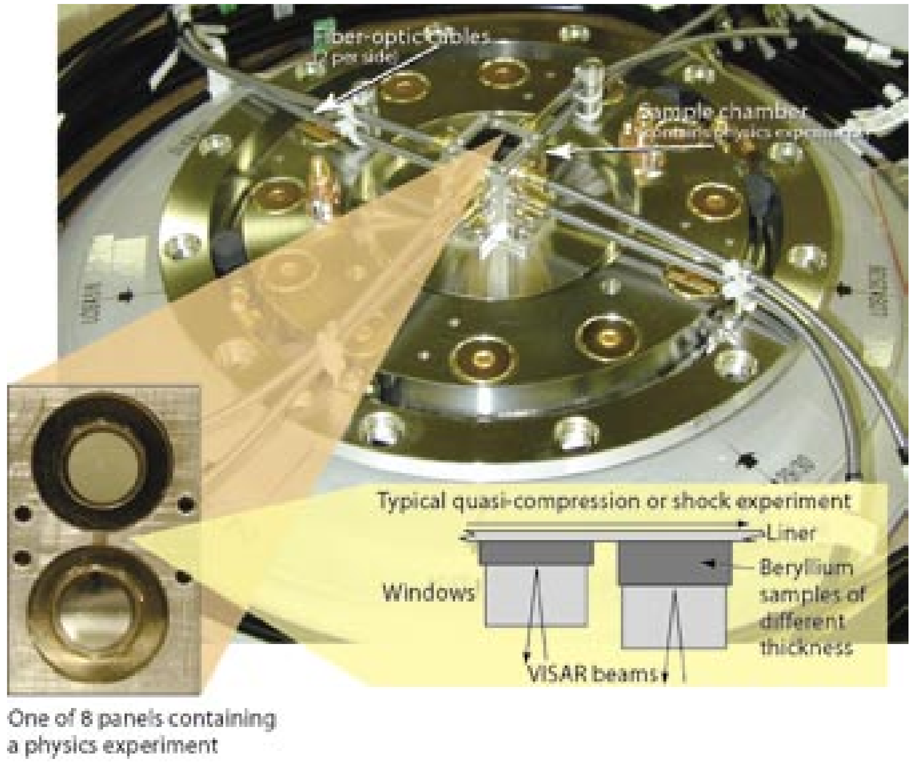
Figure 3. A typical experiment using a vacuum hohlraum with its outside wall populated by a number of experiments. This vacuum hohlraum shows four physics experiments located around the periphery of the hohlraum body. Three experiments are serviced by fiber-optic shock pins that are contained within massive radial structures (the brass-mounting hardware shown in the figure). There are also several apertures covered with foils and a low-density foam physics experiment to be radiographed by the ZBL system. The radiograph of the foam is taken as a radiation-driven shock passes radially through it.

Materials Experiments

For dynamic materials studies, the current is transmitted through the sample and then returned to the capacitor bank through a low-impedance circuit. The conductor wall is the material sample under study. The magnetic field generated between the central rod and the conductive sample can create a pressure in the sample (which is mounted on the return conductor wall) of up to 3.25 Mbar (in copper). This pressure can be used in shockless ICEs. When used in a flyer-plate mode for subsequent impact on material samples in past experiments, the Z accelerator has produced up to 28-km/s velocities in the flyer plate. In either event, the subsequent response of the material under study is used to accurately determine the equation of state of a material to ensure the integrity of simulations. P Division and DX Division use this configuration with the shock physics group at SNL to study many materials.

Several experiments conducted using the Z accelerator are discussed in detail in the project descriptions in this activity report.

Figure 4. Four sample panels are arranged in a square pattern with each of the four panels having two samples under test. In the pictured experiment, beryllium samples are in intimate contact with the aluminum current-carrying conductor. The beryllium samples are subjected to quasi-isentropic compression. The particle velocity of the beryllium/window interface is recorded using VISAR. By conducting experiments with varying thicknesses of beryllium, we can determine a complete understanding of the isentrope of beryllium.



Acknowledgment

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